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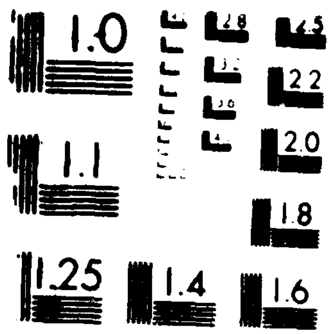

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Gastric emptying during exercise: effects of acute heat stress, acclimation and hypohydration

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Abstract

To determine the effects of acute heat stress, heat acclimation and hypohydration on the gastric emptying rate of water (W) during treadmill exercise, ten physically fit men ingested 400 ml of W prior to each of three 15 min bouts of exercise (treadmill, ~50% $\dot{V}O_{2\ max}$) on five seperate occasions. Stomach contents were aspirated after each exercise bout. Before heat acclimation (ACC), experiments were performed in a neutral (18°C), hot (49°C) and warm (35°C) environment. Subjects were euhydrated for all experiments before ACC. After ACC, the subjects completed two more experiments in the warm (35°C) environment; one while euhydrated and a final while hypohydrated (5% of body weight). The volume of ingested water emptied into the intestines was inversely correlated ($P<0.01$) with the rectal temperature ($r=-0.76$) and heart rate ($r=-0.88$) at the completion of each exercise bout. The following new observations were made: 1) *exercise in a hot (49°C) environment* impairs gastric emptying rate as compared to a neutral (18°C) environment, 2) exercise in a warm (35°C) environment does not consistently affect gastric emptying before or after heat acclimation, but 3) exercise in a warm environment when hypohydrated reduces gastric emptying rate. Reductions in gastric emptying appeared to be related to the severity of the thermal and cardiovascular strain induced by exercise/heat stress.

Index terms. gastrointestinal absorption; thermal strain; cardiovascular strain; fluid replacement; environment; dehydration

Introduction

During exercise, core temperature increases in proportion to the metabolic intensity of the activity (18). In order to minimize the rise in core temperature, sweat is secreted to dissipate (via evaporation) the metabolically released heat. During prolonged exercise in the heat, sweat rate (and thus body water loss) can exceed 1.0 $l \cdot m^{2-1} \cdot hr^{-1}$ (1,3). Concomitant with this reduction in body water is an increase in both thermal and cardiovascular strain, and a decrease in performance during exercise in the heat (27). Moreover, core temperature and responses during exercise increase linearly with the severity of hypohydration, primarily due to a corresponding decrease in blood volume and hyperosmolality which act to decrease cutaneous blood flow and sweat rate (8,12,16,28).

The ingestion of fluids during prolonged physical exercise has been shown to minimize the magnitude of hypohydration and the associated thermal and cardiovascular strain (3,11,20). It has been generally assumed that fluid ingested during exercise/heat stress will be readily absorbed by the gut. In a recent study, however, Owen et al. (19) found an increase in the gastric residue recovered following treadmill exercise performed in a warm [35°C, 20-50% relative humidity (r.h.)] as compared to neutral (25°C, 20-50% r.h.) environment. Although gastric emptying was assessed from only a single residue obtained immediately following 2 h of exercise and fluid ingestion, these findings are not suprising as reductions in the gastric emptying rate would be expected to accompany the sympathetically-mediated splanchnic vasoconstriction during an acute exercise/heat stress (23,24).

It is well established that heat acclimation reduces the thermal and cardiovascular strain associated with a given exercise-heat stress (15,21,23,25,30). In addition, heat acclimation may result in a reduced

sympathetic output (pressor response) at a given point in time during exercise in the heat. As a result, splanchnic blood flow could be greater in heat acclimated than unacclimated subjects during an exercise/heat stress (23). This raises the question that, if acute exercise/heat stress reduces gastric emptying, does heat acclimation attenuate this reduction? In contrast, hypohydrated individuals probably experience an increased pressor response necessary for maintenance of adequate cerebral oxygen delivery during exercise in the heat. An increased pressor response would serve to compromise splanchnic blood flow and gastric emptying rate. On the other hand, hypohydration could act to increase absorption rate and, therefore, gastric emptying rate due to increases in plasma osmotic and oncotic pressures. These increased plasma pressures could act to enhance water movement from the gut to the vascular space.

The present study examined the influence of exercise/heat stress on the gastric emptying rate of water in unacclimated, heat acclimated and hypohydrated subjects. The findings of this study have direct implications for hydration and rehydration proceedures to be employed by athletes, workers and military personnel engaged in physical activity.

Methods

Subjects. Ten males volunteered for this study after being informed of the requirements and possible risks associated with this research. One week prior to experimental testing, each subject's maximal oxygen uptake ($\dot{V}O_{2\ max}$) was determined from a progressive treadmill test (28). In addition, nude body weights were obtained every morning throughout the study. These body weights were used to establish base-line data that represented euhydration for each subject. Subject characteristics are presented in Table 1. The study was

conducted in Natick, MA from late March to early May in order to minimize any effects of natural heat acclimatization.

Experimental design. All experiments were completed following a 12-16 h overnight fast. Upon reporting to the test chamber, the subjects were intubated with a number 14 French, Levine gastric tube through the nasal passage. Each subject ingested 200-300 ml of water to facilitate the intubation procedure and to aid in the subsequent removal of the fasting gastric residue. Once intubated, the subjects completed a 10 min warm-up treadmill run (6 mph, 0% grade). This procedure has previously proven effective in eliminating any reduction in the initial gastric emptying rate that may occur due to an overnight fast or lack of physical activity (17). After the warm-up exercise, stomach contents were removed via aspiration with a 50 ml syringe. The nasogastric tube was moved systematically within the stomach during aspiration to insure complete evacuation of the gastric residue.

Water served as the test drink for all trials. The drinks were administered cold at ~5°C and contained 25 $mg \cdot l^{-1}$ of phenol red, a nonabsorbable marker (29). The design for all experiments was the same. After completing the warm-up exercise, the subjects ingested 400 ml of water and immediately performed 15 min of treadmill exercise (~50% $\dot{V}O_{2\ max}$). Immediately post exercise, gastric contents were aspirated. A second 400 ml of water was then ingested and the process repeated with each subject completing a total of three 15 min exercise bouts per experiment. The reliability of this method for measuring the rate of gastric emptying has previously been reported (2). During all experiments, rectal temperature was monitored via a thermistor inserted 10 cm beyond the anal sphincter. If rectal temperature exceeded 39.5°C at any time during the experiments and/or acclimation sessions (described below), testing of that subject was discontinued for the day and the subject was removed to a cool environment. Heart rate (bpm) was obtained via

radiotelemetry and recorded during the 5th and 10th min of each 15 min exercise bout. All gastric emptying experiments were separated by at least one day of rest.

Each subject performed five gastric emptying experiments. In experiment N-UN, the unacclimated subjects performed exercise in a neutral environment (18°C, 20% r.h.). During experiment H-UN, the unacclimated subjects performed exercise in a hot environment (49°C, 20% r.h.). During experiment W-UN, the unacclimated subjects performed exercise in a warm environment (35°C, 20% r.h.). The subjects were euhydrated for all experiments performed prior to heat acclimation. Following a 7-day heat acclimation program, the subjects completed two more experiments in the warm environment (35°C, 20% r.h.); one experiment (W-ACC) while euhydrated, and a final experiment (HY-ACC) while hypohydrated by 5% of their body weight.

The heat acclimation program consisted of two 50 min treadmill exercise (~50% $\dot{V}O_{2\,max}$) bouts in the heat (49°C, 20% r.h.) separated by 10 min of rest for 7 consecutive days. During the acclimation sessions, rectal temperature and HR were monitored continuously. The subjects wore gym shorts, T-shirts, and tennis shoes during all testing. Water was provided ad libitum during the acclimation sessions.

Approximately 24 h prior to the hypohydration experiments (HY-ACC), the subjects voluntarily restricted their food and fluid consumption. In addition, during the afternoon of the day prior to experiment HY-ACC, the subjects performed light intensity exercise in a hot (49°C) environment to dehydrate to 5% of their baseline body weight. Subjects achieving a weight reduction greater than 5% were allowed an appropriate amount of fruit juices. The subjects rested during the night in a comfortable environment. The following morning subjects were weighed, provided with water if sufficiently underweight, instrumented, and instructed to sit quietly for 30 min. A small (3 ml) blood

sample was obtained (venipuncture) from an arm vein for subsequent plasma hematocrit, hemoglobin, total protein, and osmolality determination. An identical procedure for blood sampling was also carried out prior to experiment W-ACC. These measures were used to document that the subjects were hypohydrated.

<u>Physiological and biochemical analysis</u>. Heart rates were determined from electrocardiograms obtained with bipolar (CM5) chest electrodes and radiotelemetered to an oscilloscope-cardiotachometer unit (Hewlett-Packard). Maximal oxygen uptake measurements were performed with an automated system (Sensormedic Horizon MMC).

Blood samples obtained prior to the euhydrated (W-ACC) and hypohydrated (HY-ACC) experiments were placed in tubes containing 72 USP units of lithium heparin. Each blood sample was analyzed in triplicate for hemoglobin (Hemoglobinometer, Coulter Electronics), hematocrit (micro-centrifugation), plasma protein (refractometry, American Optical), and osmolality (Osmette A, Precision Systems). The percent changes in blood and plasma volume were calculated from the appropriate hematocrit and hemoglobin values (5).

Following aspiration, the volume of gastric residue was recorded and an aliquot of the residue stored at 5°C. Prior to analysis, gastric residues were centrifuged at 4°C to separate any mucous within the residue. A 1 ml sample of the supernatant was then placed in 5 ml of a water/boric acid buffer. The pH of the buffered residue solution was adjusted to 9.2 and the optical density measured spectrophotometrically at 560 nm. The ratio of the optical density of the residue to the optical density of the original drink provided quantification as to the dilution of the original drink by gastric secretion (29). In addition, the volume (ml) of ingested water emptied into the intestine (original drink emptied) and the volume of stomach secretion added to the residue was calculated. Gastric emptying rate was calculated by dividing

the volume of original drink emptied by the total time of each exercise bout (15 min). The percent of original drink emptied was determined by dividing the volume of original drink emptied by the volume of water consumed (400 ml).

Statistical analysis. Statistical comparisons were made using a repeated measures analysis of variance. If significant main effects were indicated, Tukey's critical difference was calculated to locate significant differences at the $P<0.05$. All data are presented as mean ±SE.

Results

Rectal temperature and heart rate. Rectal temperatures increased significantly during exercise for all experiments (Fig. 1). Exercise in a warm environment (35°C) in the unacclimated state (W-UN) elicited a modest rise in rectal temperature that was greater than experiments N-UN and W-ACC during the second and third exercise bouts. The rectal temperature responses in the warm environment (W-ACC) following heat acclimation were not different from values during experiment N-UN. When subjects were hypohydrated (HY-ACC), rectal temperature was higher than experiments N-UN and W-ACC by the end of the first exercise bout and remained elevated over experiments N-UN, W-UN, and W-ACC during the final two exercise bouts. Only eight of ten subjects completed the entire hypohydration experiment (HY-ACC). Data from the two subjects withdrawing from the experiment was incomplete and therefore not included in the analysis. The largest increase in rectal temperature occurred during experiment H-UN. By the end of the first exercise bout, rectal temperature was higher than experiments N-UN, W-ACC and W-UN. Rectal temperature was higher than all other experiments during the second exercise bout. Because of the extreme thermal strain during experiment H-UN, only 7 of the 10 subjects were able to complete two of the three exercise bouts before achieving a rectal

temperature of 39.5°C. No subject completed the third exercise bout.

Insert Fig. 1 about here

Table 2 presents the HR data for the three exercise bouts during each experiment. Heart rates during H-UN were significantly higher than all other experiments for bout 1 and 2. In addition, HR during HY-ACC were generally greater than experiments N-UN and W-UN. Although HR were higher during experiments W-UN and W-ACC as compared to N-UN, no differences in HR were found between experiments W-UN and W-ACC.

Following 7 days of heat exposure, final rectal temperature values during acclimation sessions were significantly lowered from 39.06 ± 0.16°C on day 1 to 38.19 ± 0.11°C on day 7. Final exercise HR values were significantly decreased from 155 ± 4 bpm on day 1 to 136 ± 3 bpm on day 7. Rectal temperatures and HR were not significantly different between days 5, 6 and 7, and, as such, heat acclimation was accepted as being complete.

Insert Table 2 about here

Gastric emptying: acute exercise/heat stress. Figure 2 presents the volumes and percentages of original drink emptied during experiments N-UN, H-UN and W-UN. The volume of original drink emptied averaged 315.3 ± 21.3 ml for the three exercise bouts during experiment N-UN, corresponding to a mean emptying rate of 21.0 ± 1.4 ml/min (Table 3). In contrast, the volumes of original drink emptied were less during experiment H-UN as compared to N-UN in bout 1 and experiments N-UN and W-UN in bout 2, corresponding to a gastric emptying rate during H-UN of 13.9 ± 2.0 ml/min. Consequently, the percentage of original drink emptied during H-UN averaged only 52% as compared to 79% during N-UN. The gastric emptying responses during experiment W-UN were intermediate to experiments N-UN and H-UN, being less than N-UN only during the second exercise bout (Fig. 2).

Insert Fig. 2 and Table 3 about here

<u>Gastric emptying: heat acclimation and hypohydration</u>: All ten subjects achieved the prescribed level of hypohydration prior to experiment HY-ACC. Table 4 gives the resting values of blood constituents when the subjects were euhydrated and 5% hypohydrated. Values for hemoglobin, hematocrit, osmolality and plasma protein were greater prior to experiment HY-ACC as compared to W-ACC. In addition, blood volume was reduced by 15.5% and plasma volume by 22.8% when hypohydrated.

Table 4 about here

Figure 3 presents a comparison of the volume of original drink emptied during experiments W-UN, W-ACC and HY-ACC. No differences were found between experiments W-ACC and W-UN for any exercise bout. Emptying rates averaged 18.9 ± 1.1 ml/min and 20.4 ± 1.1 ml/min for experiments W-UN and W-ACC, respectively. In contrast, the volume of original drink emptied during the second and third exercise bout of experiment HY-ACC was reduced as compared to experiment W-UN and W-ACC. The emptying rate during HY-ACC averaged 15.7 ± 1.9 ml/min, corresponding to only 59% of the original drink emptied.

Fig 3 about here

Table 3 presents the mean values for the volume of fluids added by the stomach (stomach secretions) during each experiment. Stomach secretions were consistently reduced during experiment HY-ACC, being lower than all experiments during bout 1, and experiment N-UN during bouts 2 and 3.

To determine the relationship between gastric emptying and the thermal and cardiovascular strain, data from all experiments was pooled. A negative correlation ($r=-0.-76$, $P<0.01$) was found between the final exercise rectal temperature and the corresponding volume of original drink emptied for each exercise bout (Fig. 4). In addition, a comparison of the HR values obtained during the 10th min of exercise with the volumes of original drink emptied revealed a negative correlation ($r=-0.88$, $P<0.01$).

Discussion

The present study emphasizes the need to ingest fluids prior to the development of dehydration and high core temperatures during athletic, industrial and/or military activities. In conditions where the demand upon the thermoregulatory system is increased, gastric emptying rate decreases thereby limiting the ingested fluid's effectiveness in defending plasma volume and replacing depleted body water stores. These findings are consistent with Adolf's (1) early ideas concerning forced rehydration. Thirst is known to be a poor index of body water requirements such that ad libitum water intake during exercise in the heat results in an incomplete replacement of body water losses (1,20). In addition, as little as a 2% reduction in body weight induced by dehydration elevates core temperatures during an exercise/heat stress as compared to euhydration (27). Thirst (and therefore voluntary fluid intake) is probably not perceived until similar levels of body water deficit (2%) have been incurred (1). Furthermore, this delay in rehydration (voluntary dehydration) is greater in individuals when unacclimated to exercise in the heat (6,13). Thus, individuals experiencing the greatest thermoregulatory strain during an activity will incur the largest body water losses. Consequently, gastric emptying rate will decrease and fluid gains to the body will be minimized. Therefore, forced hydration during the early stages of an exercise/heat stress is important, not only to avoid voluntary dehydration, but to maximize the bioavailability of the ingested fluids.

Previous studies have reported marked improvements in thermoregulation and exercise performance in the heat when individuals consumed water during the activity (3,11,20). Although gastric emptying was not measured, the authors (3,11,20) attributed these findings to the effectiveness of the ingested water

in minimising water losses incurred by dehydration. Despite these previous reports regarding the long-term benefits of fluid replacement, the results of the present study demonstrate that gastric emptying rate is greatly reduced when exercise is performed in a hot (49°C) environment. In support of this finding, Owen et al. (19) recently reported a marked increase in the volume of gastric residue recovered immediately following 2 h of exercise in the heat (35°C) as compared to a comfortable environment (25°C). In the present study, however, exercise at a similar ambient temperature (35°C, experiment W-UN) did not significantly influence the gastric emptying rate as compared to exercise in the neutral environmental (18°C). This apparent discrepancy may be explained by the fact that, in the study by Owen et al. (19), relative humidity ranged from 30-50% near the end of each 2 h run while, in the present study, relative humidity was maintained at 20% during all experiments. In addition, treadmill exercise was performed at 65% of $\dot{V}O_{2\,max}$ while all exercise bouts in the present study were performed at 50% $\dot{V}O_{2\,max}$. Consequently, the greater thermal strain experienced by their subjects (19) resulted in an increase in rectal temperature from ~38.50 to ~39.50 during the final hour of exercise, similar to the responses observed in our subjects during experiment H-UN (Fig. 1).

The mechanism by which acute heat stress impairs gastric emptying rate during exercise remains open to speculation. Exercise in the heat is characterized, among other physiological responses, by a redistribution of cardiac output away from the splanchnic region, most likely due to increase sympathetic activity (23,24). This compensatory vasoregulation away from the gut is accompanied by an increase in cutaneous blood volume and flow to improve dry heat exchange (22). A reduction of splanchnic blood flow could compromise intestinal fluid absorption. Because the rate of fluid absorption in the intestine regulates the delivery rate of fluids from the stomach, presumably

via a negative feedback mechanism (4,14), a reduction in intestinal absorption likely decreases the emptying rate of fluids from the stomach. In support of this hypothesis, all ten subjects complained of moderate to extreme gastrointestinal discomfort during experiment H-UN, indicative of some degree of splanchnic ischemia (26).

In contrast to our hypothesis, heat acclimation was not accompanied by an enhanced gastric emptying rate in experiment W-ACC compared to W-UN (Fig. 3). However, it is important to note that the gastric emtpying rate during exercise in the warm environment (35°C) prior to heat acclimation (experiment W-UN) was not different from experiment N-UN (Table 3). Thus, the relatively mild additional heat strain during experiment W-UN was insufficient in eliciting a consistent decrement in the gastric emptying rate. It seems likely that in conditions where heat stress is sufficient to impair gastric emptying (compared to temperate conditions), heat acclimation would attenuate this impairment.

Although post acclimation experiments were not performed in the hot environment (49°C), there is evidence to suggest that gastric emptying would have been facillitated by acclimation. First, heat acclimation is associated with a plasma volume expansion which could enable improved blood flow to inactive organs during exercise/heat stress (23,30). Secondly, heat acclimation lowers core temperature responses to exercise in the heat (15,21,23). Since skin blood flow is related to the core temperature during heat stress, absolute cutaneous blood flow may be decreased post-acclimation (15,23,25). This reduction may occur at a given point in time despite the well documented increased flow for a given core temperature after acclimation (21). Moreover, reductions in plasma renin activity parallel the decreases in HR with acclimation, thereby possibly reducing any direct vasoconstrictor effects of circulating angiotensin II on splanchnic blood flow (7,9,10). Any such decrease in skin blood flow, plasma renin activity or sympathetic activity (23)

accompanying heat acclimation would be expected to increase splanchnic blood flow and, therefore, gastric emptying.

In addition to impairing the thermoregulatory response and reducing stomach secretions, hypohydration decreased the gastric emptying rate (Fig 3). Sweating induced dehydration results in a reduced plasma volume and an increase in plasma osmolality (Table 4). However, plasma hyperosmolality would likely enhance fluid absorption from the intestine due to the elevated osmotic gradient between the blood perfusate and ingested fluids and therefore, does not account for the observed reduction in gastric emptying. On the other hand, the hypohydration-mediated decrease in plasma volume would be expected to elicit a near-maximal pressor response (to maintain cerebral blood flow) during an exercise/heat stress, thereby limiting splanchnic perfusion. In addition, Francesconi et al (10) have shown that plasma renin activity and aldosterone concentration increase with the level of water deficit during exercise/heat stress. Therefore, increases in angiotensin II and perhaps epinephrine would likely contribute to splanchic vasoconstriction and reduced flow during an exercise/heat stress when hypohydrated as compared to euhydrated.

In the present investigation, demands upon the thermoregulatory system were altered by varying the environmental conditions, acclimation state and hydration state of the subjects. As evident from Fig. 4, the volume of original drink emptied correlated well with both core temperature and HR from all experiments, independent of treatment. Thus it appears that the reduction in gastric emptying during exercise is dependent upon the severity of the thermal and cardiovascular strain induced by an individual's hydration state, level of activity and the surrounding environmental conditions. This variation in thermal strain may mediate a graded pressor response (as reflected by elevated HR) to redistribute blood flow from the splanchnic region to the skeletal muscle and cutaneous vasculature, thereby reducing gastric emptying.

In summary, these data represent several new findings concerning the gastrointestinal absorption of water during exercise: 1) exercise in a hot environment (49°C, 20% r.h.) severely limits gastric emptying while exercise in a warm environment (35°C) only slightly impairs fluid uptake as compared to a neutral environment (18°C); 2) heat acclimation does not significantly influence fluid absorption during exercise performed in a warm environment; and 3) moderate hypohydration (5%) reduces gastric emptying during exercise in a warm environment. In conclusion, reductions in gastrointestinal absorption appear to be related to the severity of the thermoregulatory and cardiovascular strain induced by an exercise/heat stress.

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Table 1. Characteristics of subjects (N=10).

Characteristics	Mean
Age, yr	19.3±0.4
Height, cm	172.6±2.3
Weight, kg	66.1±1.4
$\dot{V}O_{2\ max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.9±0.8

Values are means ±SE (N=10). $\dot{V}O_{2\ max}$, maximum oxygen consumption.

Table 2. Heart rate during exercise

Experiment	Bout 1		Bout 2		Bout 3	
	5'	10'	5'	10'	5'	10'
N-UN	146	150	145	151	146	152
	±3	±3	±3	±3	±3	±3
H-UN	171*	187*	196*	201*	—	—
(N=7)	±9	±7	±5	±6		
W-UN	153	160^{τ}	159^{τ}	164^{τ}	159^{τ}	164^{τ}
	±4	±4	±4	±4	±6	±5
W-ACC	151	157	153	159^{τ}	160^{τ}	160^{τ}
	±3	±4	±3	±3	±4	±3
HY-ACC	158^{τ}	170^{δ}	167^{δ}	173^{δ}	170^{δ}	178^{δ}
(N=8)	±6	±6	±6	±6	±5	±5

Values are mean ±SE (N=10) for heart rate (bpm) during the 5th and 10th min of each 15 min treadmill exercise session for experiments N-UN (neutral environment, 18°C), H-UN (hot environment, 49°C preacclimation), W-UN (warm environment, 35°C preacclimation), W-ACC (warm environment, 35°C post acclimation), and HY-ACC (5% hypohydrated, 35°C post acclimation). * Significantly ($P<0.05$) different from all experiments. τ Significantly different from experiment N-UN. δ Significantly different from experiment N-UN and W-UN.

Table 3. Emptying rates and stomach secretions

Experiment	Emptying rate ($ml \cdot min^{-1}$)	Stomach Secretions (ml) Bout 1	Bout 2	Bout 3
N-UN	21.0	58.9	41.7	37.1
	±1.4	±6.7	±7.1	±5.7
H-UN	13.9	48.0	33.9	———
(N=7)	±2.0	±3.1	±2.3	
W-UN	18.9	38.3*	33.6	25.7
	±1.1	±4.9	±6.5	±4.5
W-ACC	20.4	42.0*	25.8	29.2
	±1.1	±4.5	±5.2	±4.9
HY-ACC	15.7	21.6$^{\tau}$	17.3*	13.[illegible]*
(N=8)	±1.9	±2.8	±3.7	±3.3

Values are mean ±SE (N=10) for the average emptying rate ($ml \cdot min^{-1}$) during each experiment and the volume (ml) of stomach secretions within the gastric residues obtained after each 15 min exercise session for experiment N-UN (neutral environment, 18°C), H-UN (hot environment, 49°C preacclimation), W-UN (warm environment, 35°C preacclimation), W-ACC (warm environment, 35°C post acclimation), and HY-ACC (5% hypohydrated, 35°C post acclimation). * Significantly ($P<0.05$) different from experiment N-UN. $^{\tau}$ Significantly different from all experiments.

Table 4. Blood constituents in the euhydrated and 5% hypohydrated state

Hydration state	Blood Parameter					
	Hb $g \cdot 100ml^{-1}$	Hct %	Osm $mosmol \cdot l^{-1}$	PP $g \cdot 100ml^{-1}$	% ΔBV	% ΔPV
Euhydrated	14.2 ±0.3	43.9 ±0.6	280 ±1	7.1 ±0.1		
Hypohydrated	16.8* ±0.5	50.0* ±1.2	287* ±2	8.8* ±0.3	-15.5 ±1.4	-22.8 ±2.2

Values are mean ±SE (N=10) for hemoglobin (Hb), hematocrit (Hct), osmolality (Osm), plasma protein (PP), and percent change in blood volume (% ΔBV) and plasma volume (% ΔPV) from blood samples obtained 30 min prior to experiments WPOST (euhydrated) and HYPOST (5% hypohydrated). * Significantly ($P<0.05$) different from corresponding euhydrated value.

Figure legends

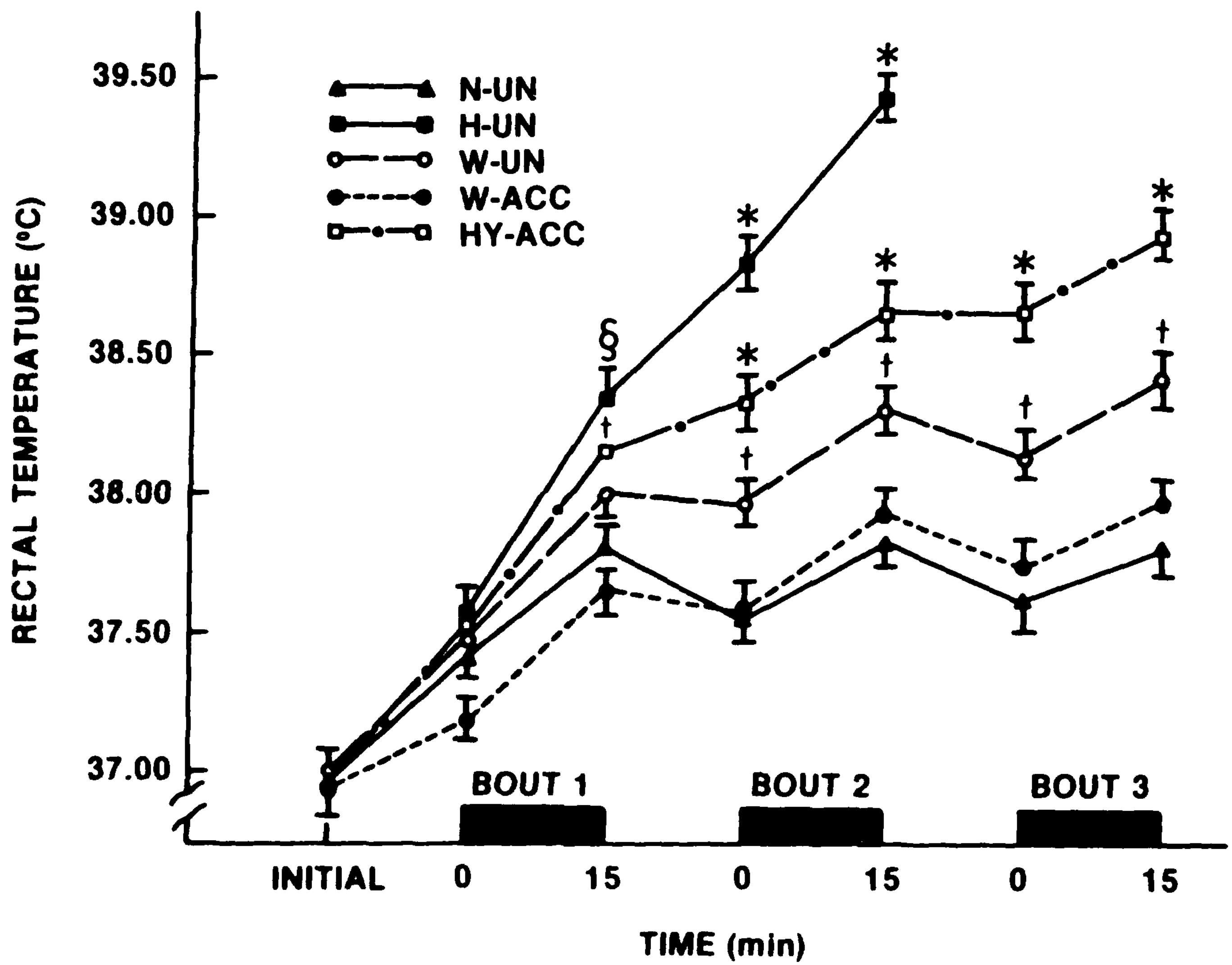
Fig. 1. Rectal temperature (°C) values (mean ± SE) for experiments N-UN (18°C, unacclimated), H-UN (49°C, unacclimated), W-UN (35°C, unacclimated), W-ACC (35°C, acclimated), and HY-ACC (35°C, 5% hypohydrated and acclimated). * Significantly different ($P<0.05$) from all other experiments. τ Significantly different from experiments N-UN and W-ACC. § Significantly different from N-UN, W-ACC and W-UN.

Fig. 2. Volumes (ml) and percentages of original drink emptied during experiments N-UN (18°C, unacclimated), H-UN (49°C unacclimated), and W-UN (35°C, unacclimated). * Significantly different ($P<0.05$) from experiment N-UN. τ Significantly different from experiments N-UN and W-UN.

Fig. 3. Volumes (ml) and percentages of original drink emptied during experiments W-UN (35°C, unacclimated), W-ACC (35°C, acclimated), and HY-ACC (35°C, 5% hypohydrated and acclimated). * Significantly different from all experiments.

Fig. 4. Correlation of final exercise rectal temperatures (°C) and heart rate (bpm) recorded during the 10th min vs the corresponding volume (ml) of original drink emptied for each exercise session.

FIG. 1



39.50
39.00
38.50
38.00
37.50
37.00
RECTAL TEMPERATURE (°C)
N-UN
H-UN
W-UN
W-ACC
HY-ACC
§
*
†
BOUT 1
BOUT 2
BOUT 3
INITIAL
0
15
0
15
0
15
TIME (min)

FIG. 2

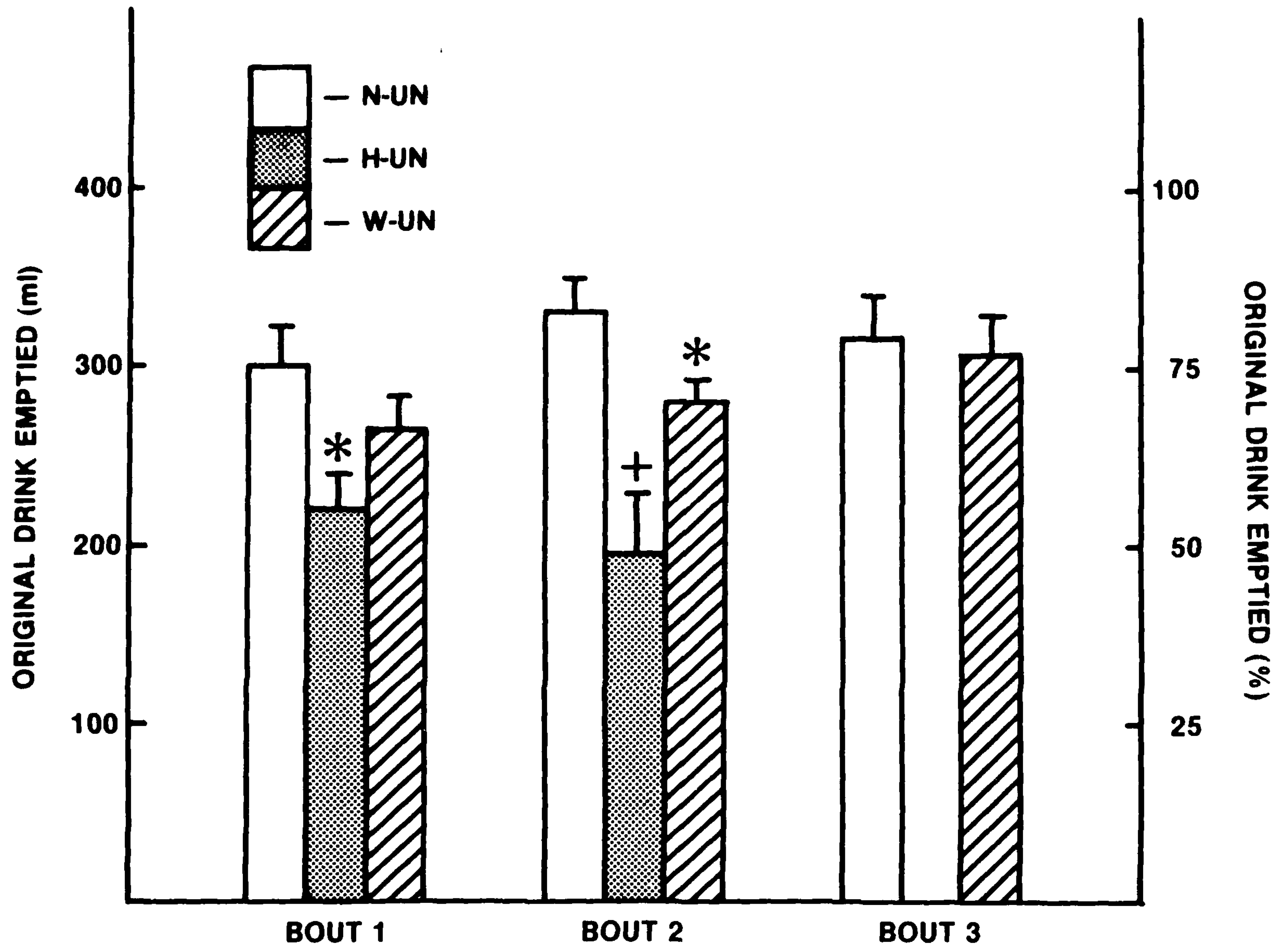
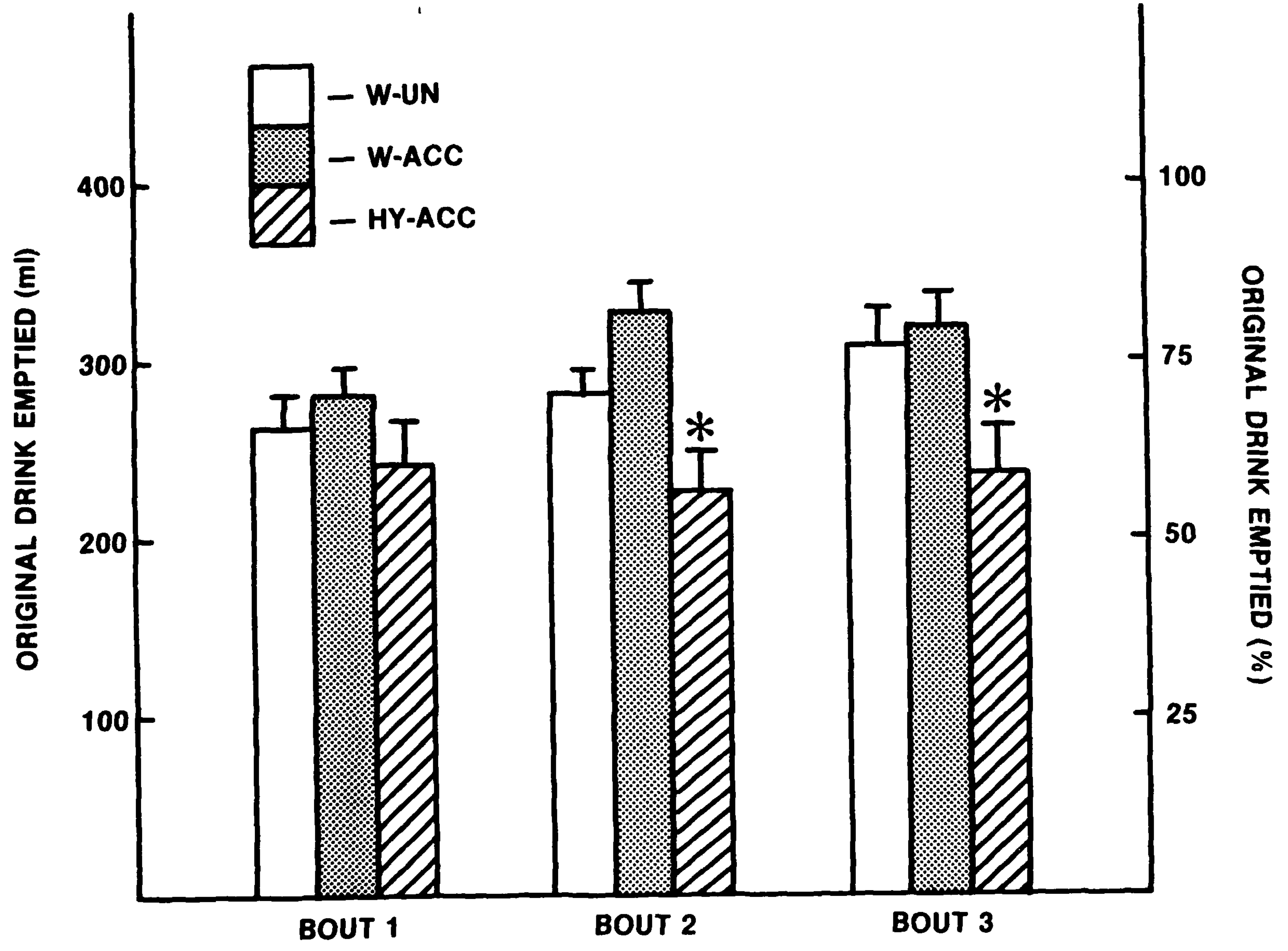
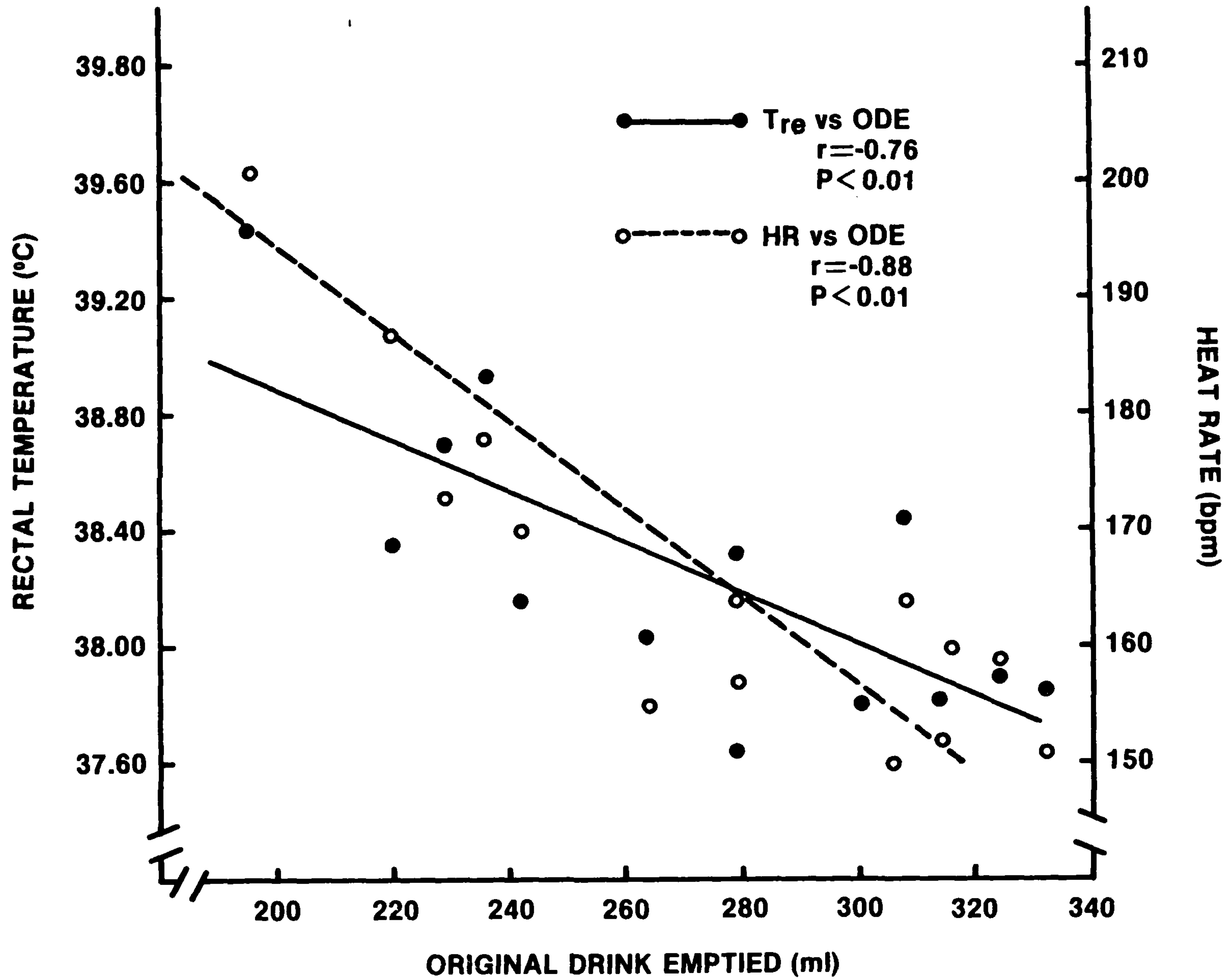

N-UN
H-UN
W-UN
ORIGINAL DRINK EMPTIED (ml)
400
300
200
100
ORIGINAL DRINK EMPTIED (%)
100
75
50
25
*
+
*
BOUT 1
BOUT 2
BOUT 3

FIG. 3



W-UN
W-ACC
HY-ACC
ORIGINAL DRINK EMPTIED (ml)
400
300
200
100
ORIGINAL DRINK EMPTIED (%)
100
75
50
25
*
*
BOUT 1
BOUT 2
BOUT 3

FIG. 4



T_{re} vs ODE
r=-0.76
P<0.01
HR vs ODE
r=-0.88
P<0.01
RECTAL TEMPERATURE (°C)
39.80
39.60
39.20
38.80
38.40
38.00
37.60
HEAT RATE (bpm)
210
200
190
180
170
160
150
200
220
240
260
280
300
320
340
ORIGINAL DRINK EMPTIED (ml)

END
FEB.
1988
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